Embedded Systems
INSTITUTE

ArtistDesign Workshop on Embedded Systems in Healthcare 2009

Elisabetta Farella

Sensing and Actuating in Assistive Environments

Abstract

Body Area Networks and Assistive Environments are attracting increasing attention as an answer to cope with issues arising from an aging population, to address prevention and early risk detection, to support people with chronic diseases or as a stimulus to provide health consciousness of people and improve their quality of life. However, interaction with end-users and caregivers must be introduced from the design phase and maintained in all implementation steps for smart system to be effective and offer viable solutions to societal needs.

Experiences from EU projects in the field of motor assessment and rehabilitation, such as FP6 SENSACTIONAAL and FP7 SMILING, are presented as an occasion to reason on trends in technologies, application scenarios and user-centered design with specific reference to body sensor networks and smart devices for real-time feedback provisioning in motor rehabilitation and training.

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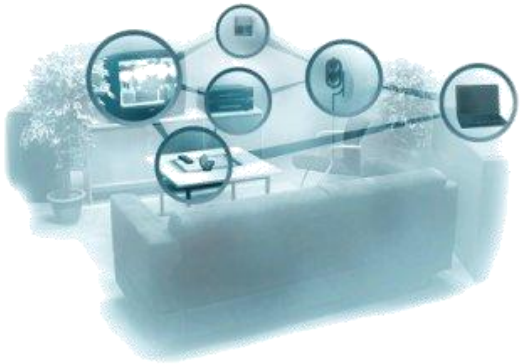
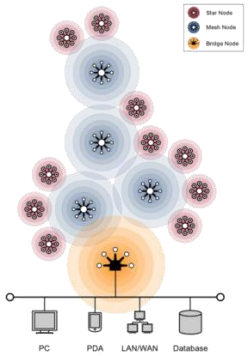


Sensing and Actuating in Assistive Environments

December 7th, 2009 *Eindhoven - The Netherlands*



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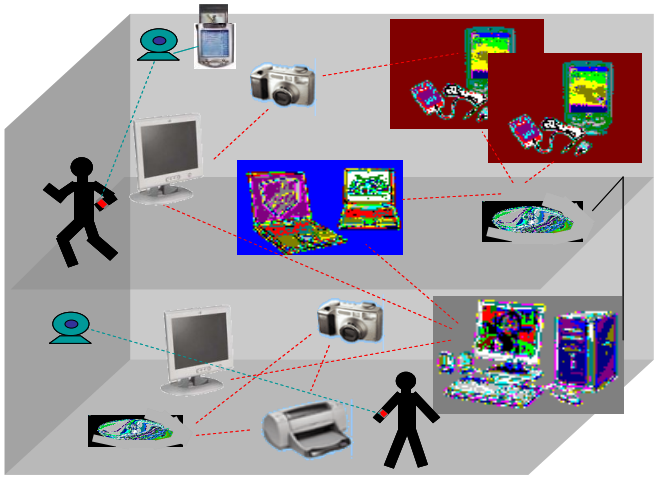
WSN enabling AmI



Ambient Intelligence
electronic environments that are sensitive and responsive to the presence of people

AmI = Ubiquitous computing + Ubiquitous Communication+ intelligent social user interfaces

Ambient intelligence envisions a world where people are surrounded by intelligent and intuitive interfaces embedded in the everyday objects around them. These interfaces recognize and respond to the presence and behavior of an individual in a personalized and relevant way.

- Smart environments need "information feed"⇒ *sensors*
- Sensor data must be communicated, stored, processed ⇒ *network*
- Networking anywhere, everywhere, little infrastructure ⇒ *wireless*

The "sensory system" of the intelligent ambient "organism"

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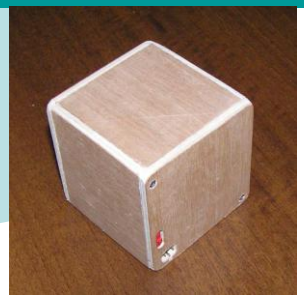
Localization, HCI, user awareness, cooperative work and playtime

Smart Objects

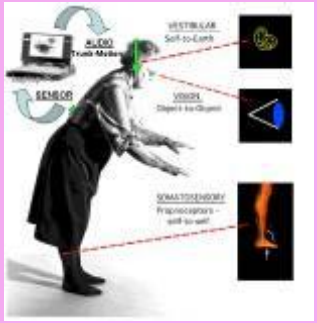


WSN as Enabling Technology

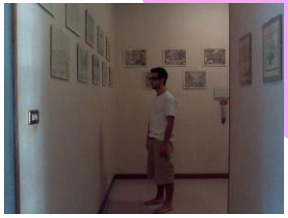
All these are possible building blocks for healthcare applications

Wearable and BAN

Gestures, Natural Interfaces, HCI

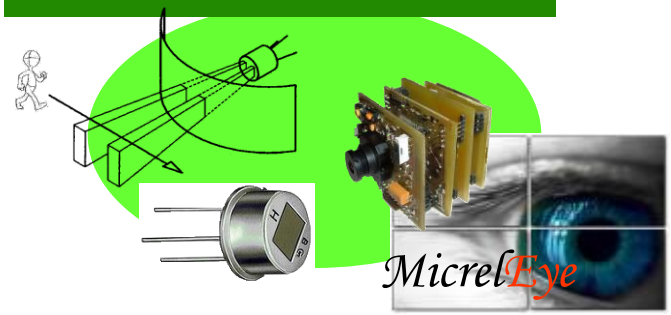


Bio-feedback, rehabilitation & training, assistive technologies

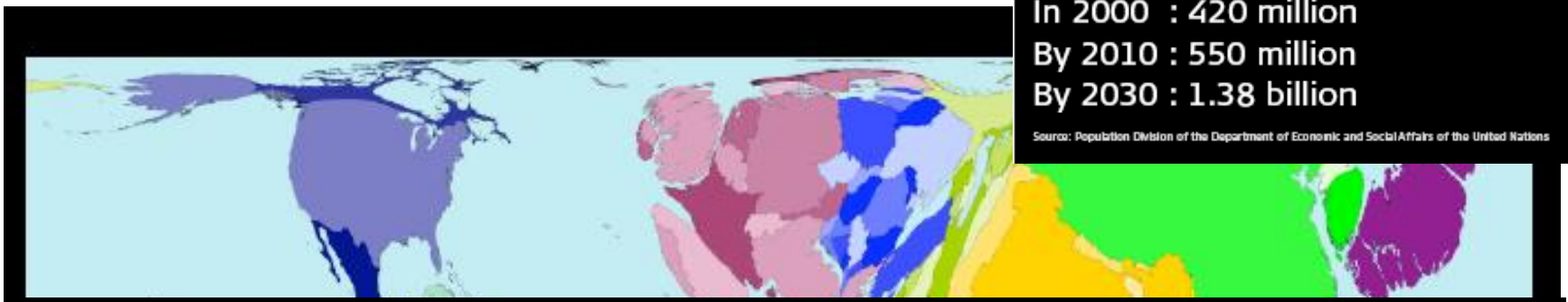


Static and dynamic posture and activity monitoring/recognition

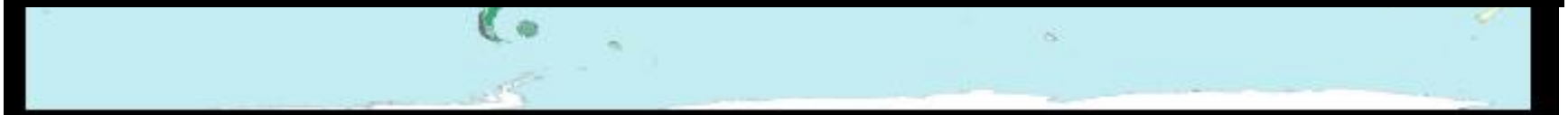
Smart Environments



Pervasive Health – Why?



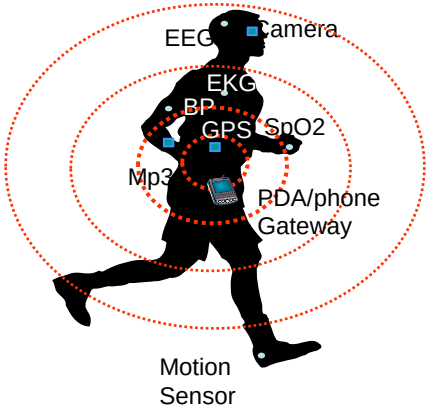
- Social challenge: to preserve for as long as possible the **autonomy** and **independency** of ageing people, their Quality of Life (and the QoL of their relatives)
- Economic challenge: to **reduce the costs** for medical assistance to elderly people



The worldwide distribution of people over 65 years old in 2002.
Source : http://www.worldmapper.org/. © SASI Group (University of Sheffield) & Mark Newman (University of Michigan)

Pervasive Healthcare: How?

Use ***Pervasive Computing*** for day-to-day healthcare management to enable ***real-time, continuous*** patient monitoring & treatment



Body Area Network

Features

- **Extends remote monitoring model** by enabling:
  - Physical presence of caregivers required only during emergencies
  - Improved coverage and ease of monitoring
- Utilize in-vivo and in-vitro **medical sensors**

Nano-scale Blood Glucose level detector Developed @ UIUC

Lifeshirt non-invasive monitoring Developed @ Vivometrics

Medical Tele-sensor can measure and transmit Body temperature Developed @ Oak Ridge National Laboratory

Applications

Home-based Care

Sports Health Management

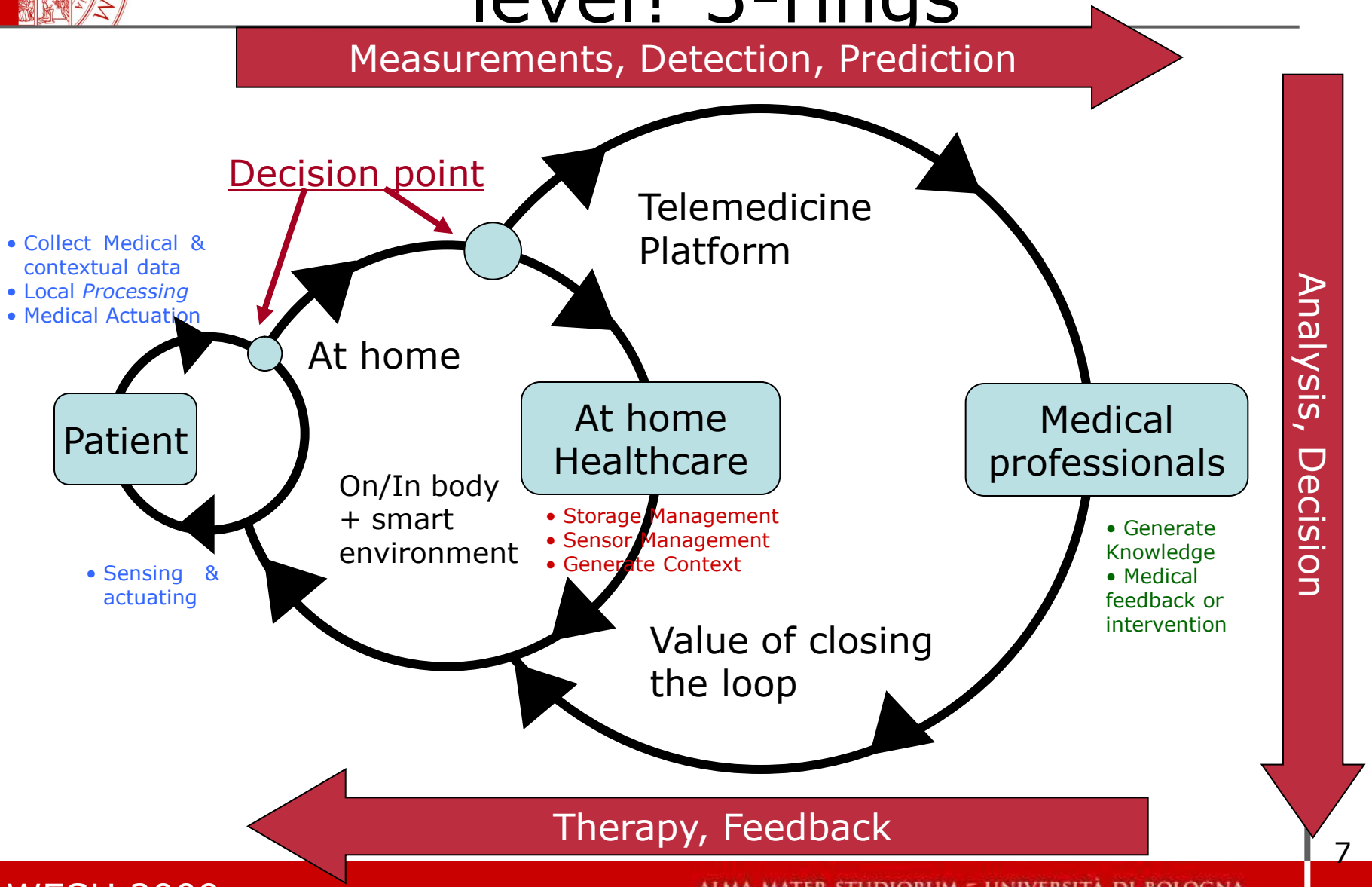
Disaster Relief Management

Medical Facility Management

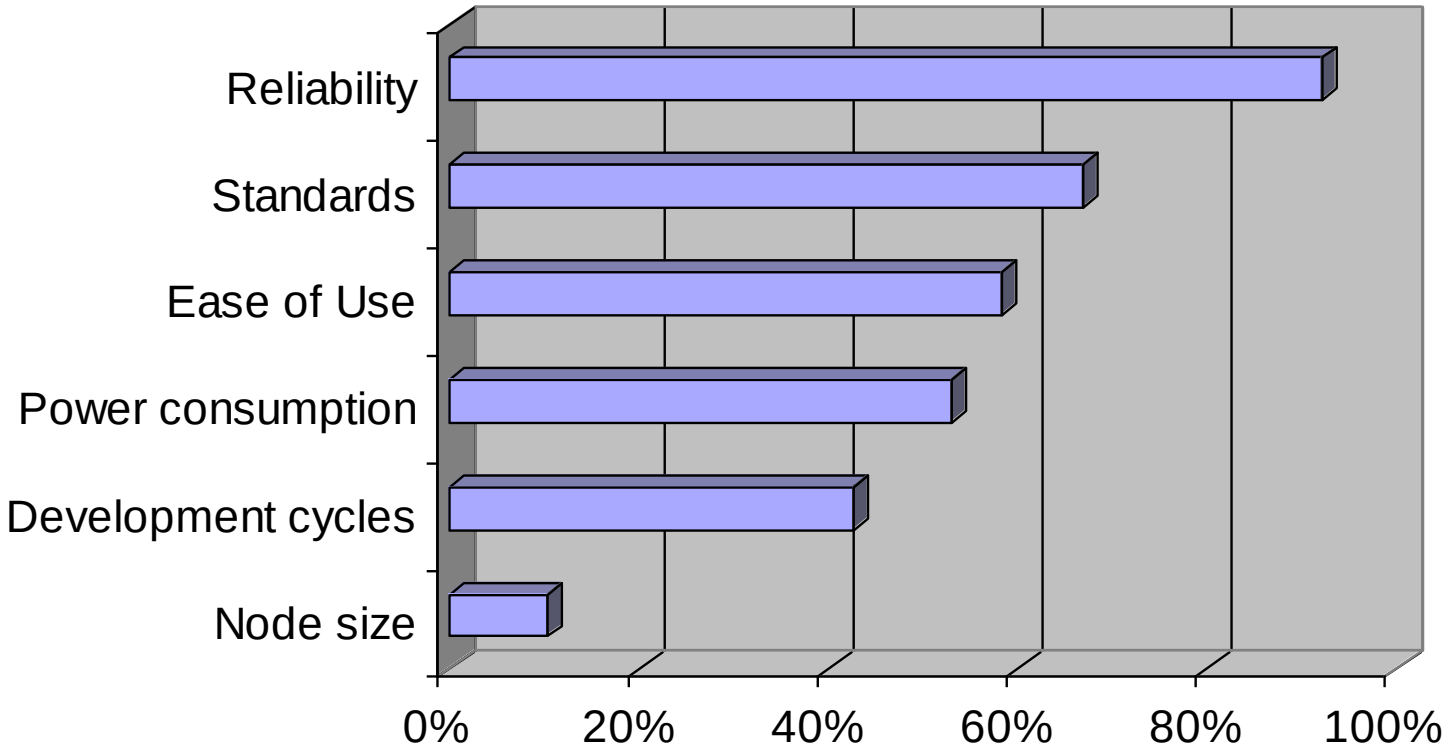
- ***Mobile*** patients. **No time & space restrictions** for health monitoring
- Better **quality of care** and reduced medical errors
- **Early detection** of disorders and actuation through automated health data analysis

GOAL: Enable independent living, general wellness and disease management.

Pervasive Healthcare: at which level? 3-rings

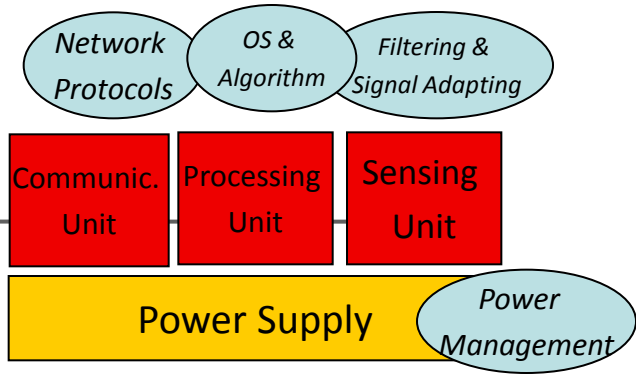


Barriers



- Usability factors: ergonomics, accessibility, costs, unobtrusiveness
- Lifetime, Mobility, Maintenance, Calibration, Overall Performance
- Interoperability

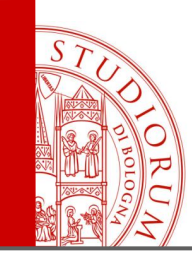
Is technology mature?



1. **The Sensor/Actuator:** A mature industry to begin with. Now low cost, low power, highly sensitive sensors, such as MEMS devices, are well down the high volume cost curve.
2. **Wireless Link:** Low cost, low power, robust wireless transceivers are being introduced at a very fast pace, but power consumption is not fully satisfactory yet. ULP microcontrollers are quite mature
3. **Energy Conversion:** Low cost energy storage and conversion devices are being launched that take advantage of silicon semiconductor cost models. Lots of room for analog design innovation.
4. **Harvesters:** Numerous energy harvesting start-ups are now funded. Harvesting devices are the least mature piece of the equation and therefore will set the pace at which Wireless Sensor/Control Networks proliferate
5. **Software programming**: not stabilized, no dominating solutions, lot of proprietary environments. Large-scale test-beds still needed

Practical experiences

- Two EU projects on motor impairments rehabilitation, training and prevention
  - **FP6 SENSACTIONAAL** - ***SENsing and ACTION to support mobility in Ambient Assisted Living***.
  - **FP7 SMILING** - ***Self Mobility Improvement in the elderly by counteracting falls***









Service de Gériatrie et
Réadaptation Gériatrique




Movement means life

Mobility problems…

- have a very negative effect on an elderly person's life and health

Accidental falls…

- represent the sixth cause of death among elderly
- it is estimated that one in three people aged 65+ is at risk of falling
- for people aged 80+ the figure increases to one in two people

Home motor training – Why?

- It has been demonstrated that *physical activity based interventions* can improve motor and cognitive functioning and decrease risk of falls in older people, both with and without age-related pathology.

- Evidence suggests more effect when interventions take place over **longer time periods**, when interventions are **individually tailored**, and when interventions also include **exercises in the home environment**.

A.J. Campbell et al., BMJ, 1997
A. Ashburn et al., JNNP, 2007

Needs to be covered

Importance to provide accessible systems and devices:

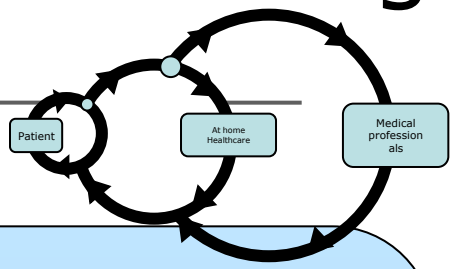
- that provide means to perform **customized**, **repetitive rehabilitation exercises directly at home** via closed-loop bio-feedback therapy. This will reduce patient discomfort and caretaker loads in terms of time and mobility.

- able to perform a **monitoring of mobility during daily life activities**. This will improve knowledge on quantity and quality of motor activity at home.

- that can remotely transmit alarm and raw data in case unrecovered **falls** are automatically detected. This will enhance daily home safety and security of elderly people living on their own and increase knowledge on falls.

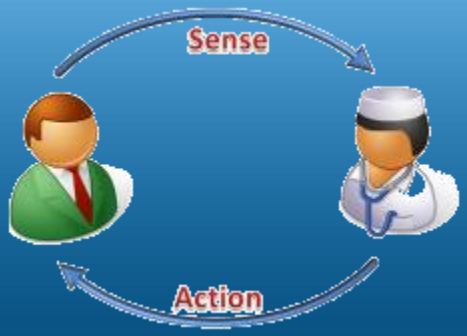
The Paradigm: Sensing & Actuating

3 scenarios in SENSACTIONAAL



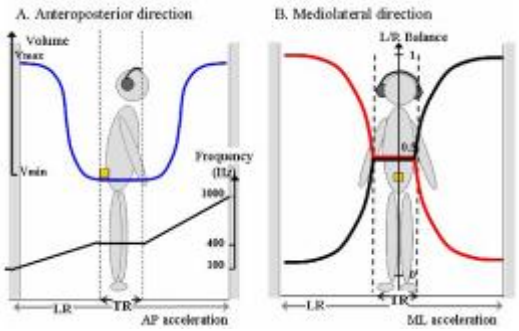
Local
(e.g. home rehabilitation and training, QoL assessment for user-awareness, short-term, real-time, etc.)

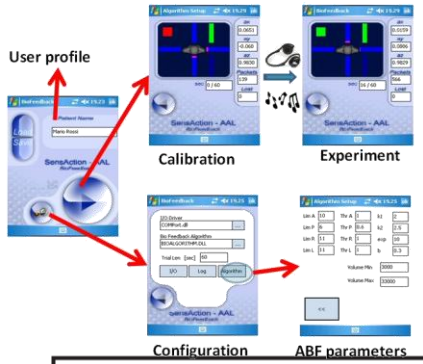
Remote
(e.g. providing awereness of patient state after treatment to caregivers, long term analysis of behaviour, off-line)

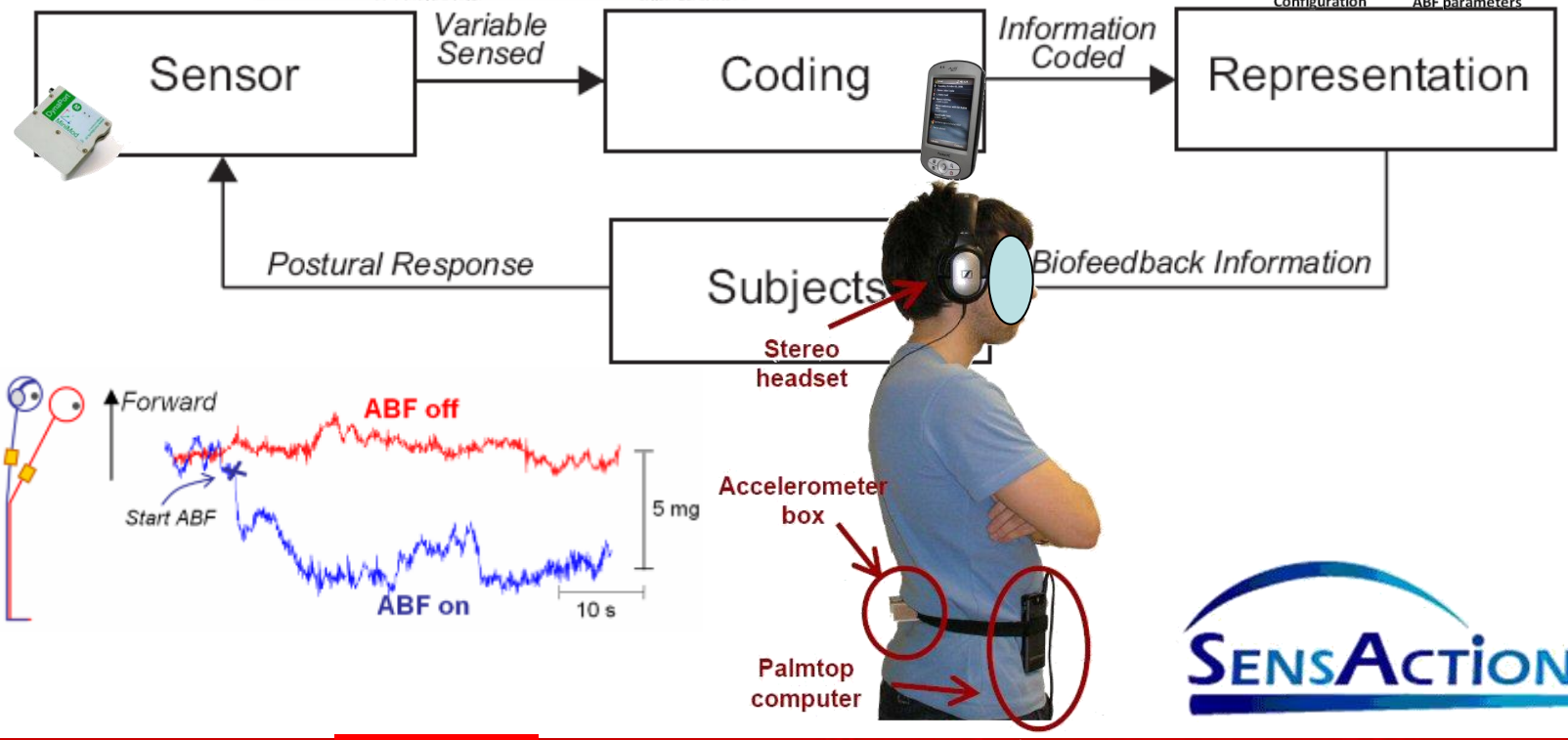


Local and Remote
(fast reactive detection of dangerous events, alarm dispatching to user and caregivers)

Closed loop scenario: Biofeedback for rehabilitation





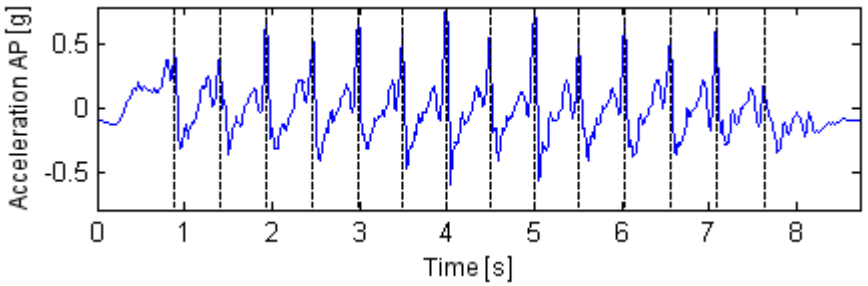


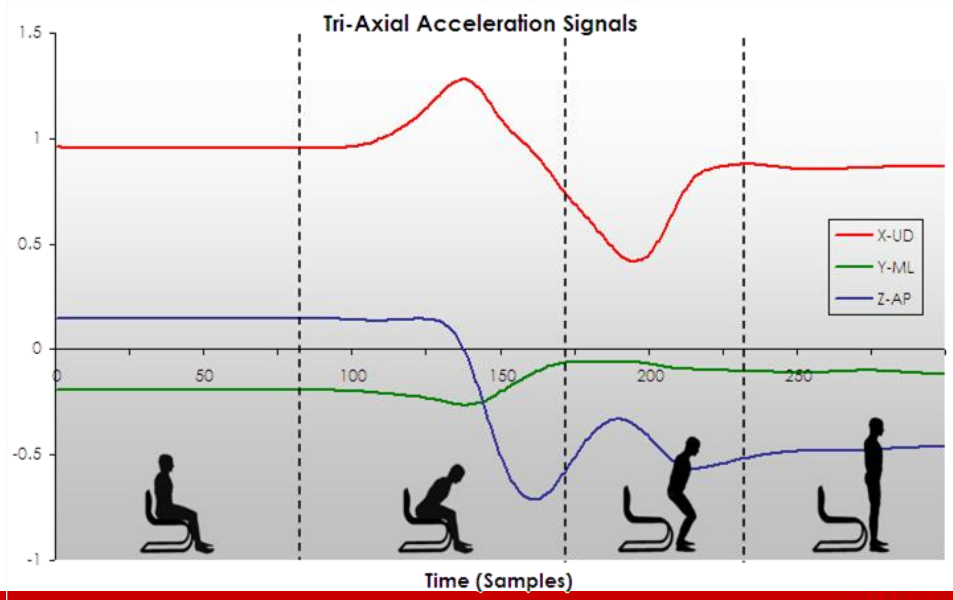
SENSACTION-AAL

Mobility Assessments

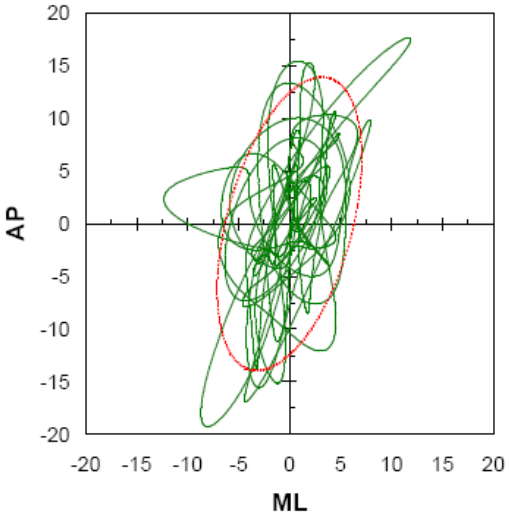
Multi-center standardised tests of standing, walking, and rising from a chair

Analyses of stepping patterns during walking





Sway related parameters during quiet standing



ABF tests on PSP and PD patients

Analyses of repeated Sit-to-Stand movements

Clinical validation trial

Methods

- **Subjects**

10 subjects with SCI, lesion level range C6-T6
Patients were randomly assigned to:
÷ TG, treatment group, 6 subjects
÷ CG, control group, 4 subjects

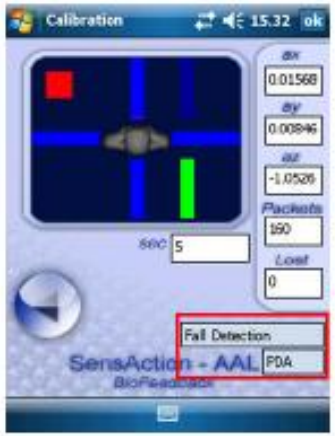
- **Protocol**

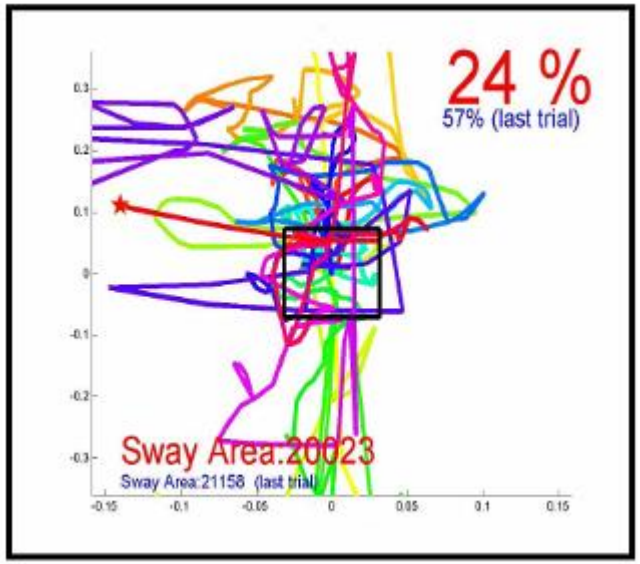
First day — Last day

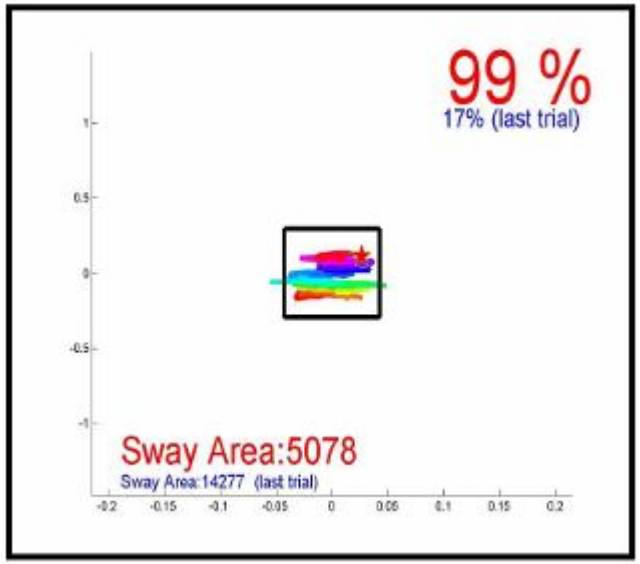
Baseline Testing

3 weeks of training
- **AVBF training for TG**
(20 min a day, in addition to the conventional therapy)
- **Conventional therapy for CG**
(120 min)

Post-Treatment Testing







First trial *Last trial*

Training @ clinical site

Aims of ABF-based training:

- To enhance upright Posture (in sitting & standing)
- To improve ADL's (sit-to-stand)
- To improve Dynamic Balance (stepping, reaching, and combination training)

- >370 training sessions in PD & PSP patients; (very) good adherence
- Training sessions in the home situation suggest feasibility of "tele-training"
- Pre-post analyses on clinical measures in 10 PD & 8 PSP patients show positive results (GDS improved of 30%)
- Sensor based outcome measures are under analysis

Moreover, activity monitoring and fall documentation:

- Mobility Monitoring during daily life activities (lying, sitting, standing, locomotion… in PD and PSP pat.
- 25 reported falls => 19 verified falls in 6 subjects.

Users' perspective

- Patients enjoyed the training
- All patients were able to correctly follow the audio information
- Some reported they were able to "still hear the feedback at home"
- They reduced their number of falls
- Increased awareness and concentration
- Well suited for different disease severity

Interaction with end-users in Close loop scenario

General architecture fixed:
Hybrid node (3acc, 3gyros), BT, SD card, PDA, audio-feedback

Prelim. Setup

AB software v1
Minimod + BT adapters

Advanced Setup

ABF software v2.3
Dynaport Hybrid

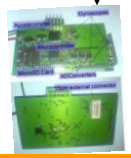
Pilot studies

Validation studies

M1 M7 M10 M12 M13 M16 M18 M22 M24 M27 M28 M36

Design
concept & exploratory prototypes

Hybrid Node v1



HW-SW development started

Hybrid + Decision Remote control

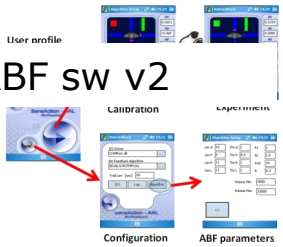
ABF v2.1
Multiple audio cues

ABF v2.2 & v.2.3
Exercises, Calibration & hearing tests, first Home Version

M27-36 refinements, assistance and tuning

Exploratory prototypes

Basic ABF sw v1 on PDA



ABF sw v2

- **ABF software final**
  - Hearing tests
  - Multiple audio cues
  - Calibration
  - Exercise (e.g. STS)
  - Opt Home version
  - Long loop sw

Again… in Long-term monitoring

First protocol of PCI analysis & analysis of long term measurements

Commercial launch of MoveMonitor

Pilot studies
Data collection
Stuttgart

M28-36 refinements, assistance and tuning

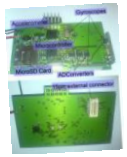
Validation studies

Validation flow

M1 M8 M11-M13 M13 M17 M18 M26 M27 M30 M31 M34

Start MoveMonitor

Hybrid Node v1



Hybrid

II prototype of Fall detection Algorithm

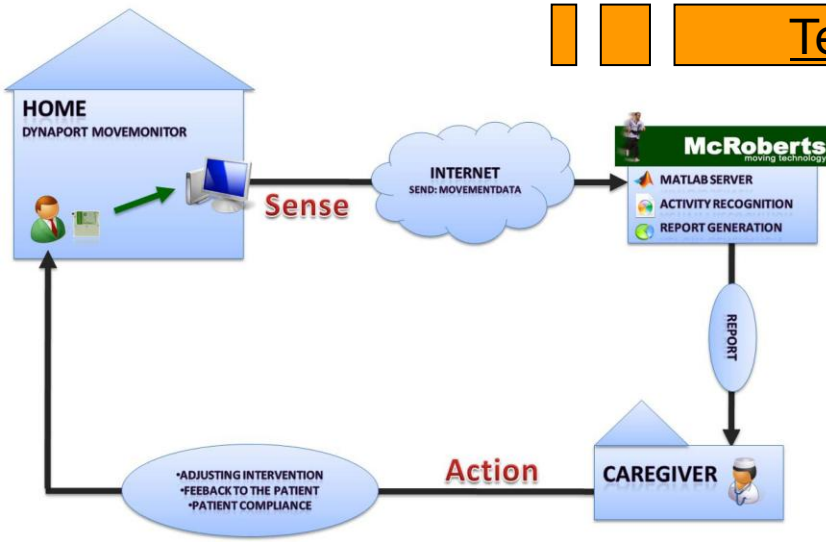
Technical flow

control development

Data analysis for activity recognition & STS phases

I prototype of Fall detection Algorithm

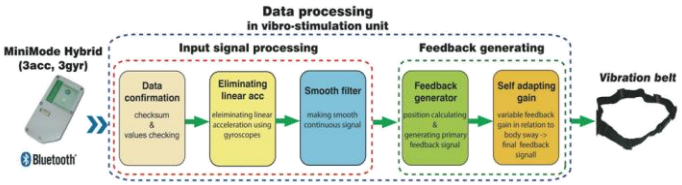
MoveMonitor v2.0



Exploration of alternative solutions

- Alternative feedbacks, hw platform, wireless solutions

Bone conductors



ABF v2.1
Multiple audio cues

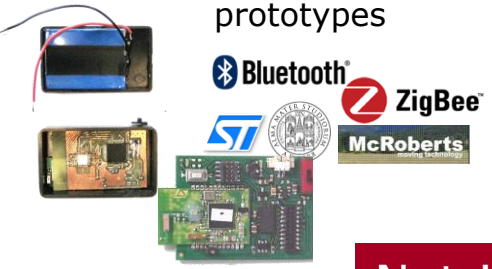
Basic audio

Vibrotactile belt v1

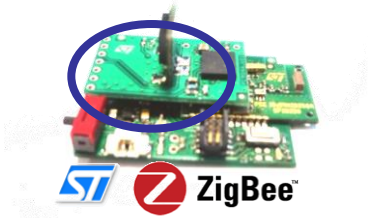
Vibrotactile belt v2

M1 — M6 — M16 — M18 — M19 — M22 — M24 — M27 — M28 M36

Design concept & exploratory prototypes



Embedded PEG



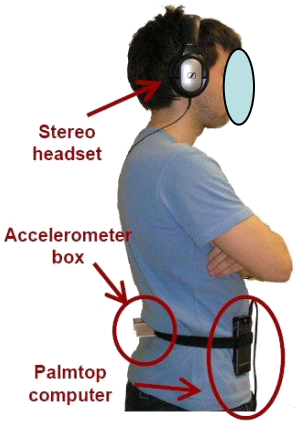
MotionBee + gyros

Vibrotactile belt hw-sw optimization

Not just an exercise-> real products and advanced prototypes!

A good example of…

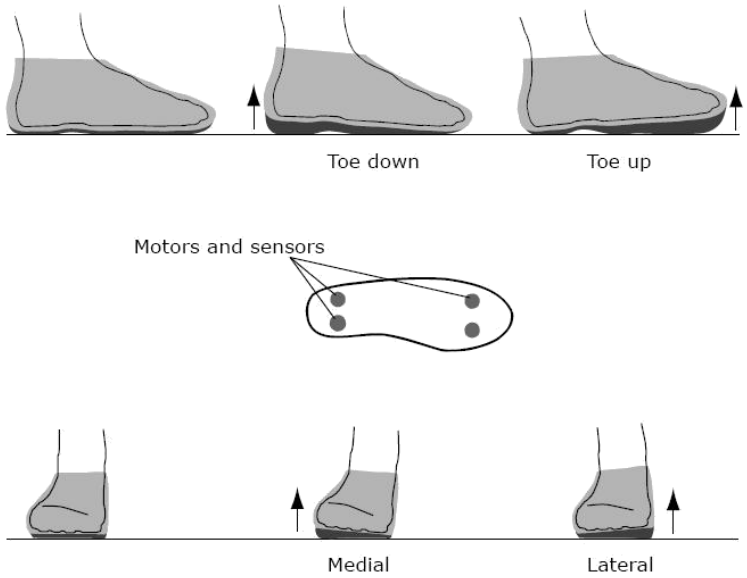
- Technology design and implementation NOT separated from its use and end-users requirements and needs
- Good practice of cooperation between industrial and academic partners – tech transfer happened bi-directionally



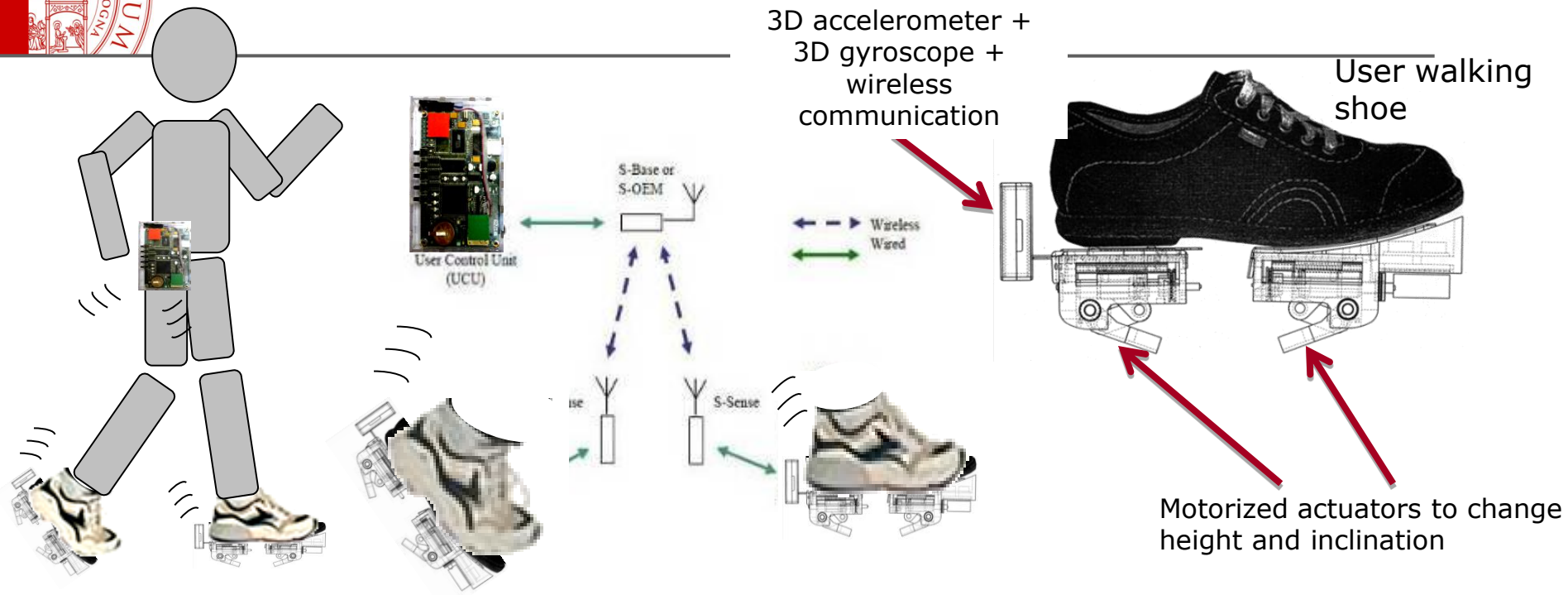
SMILING & Fall Prevention: a mechatronic training device

- FP7 SMILING aims at enhancing elderly persons capability to avoid falls by re-training patient's walking procedures.
- SMILING walking training is based on perturbations of the gait cycle to empower reaction capabilities.

The basic idea: a "shoe" able to change is height and inclination during the swing phase of gait



General Architecture



- Perturbations are changes of inclination of the shoe sole in the range +-4.5 degrees in sagittal and frontal plane and change of height up to 20 mm
- The user control unit coordinates the training:
  - Downloading a personalized training program in the shoes
  - Enabling the user to start, stop, pause the system
  - Providing feedback, support and assistance to user while performing the training

Functional flow

Phase I:
User &
clinician

Gait analyzer

Gait parameters

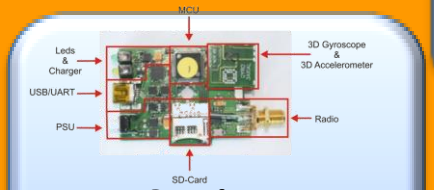
Perturbations selection

Basic gait parameters:
- Gait velocity
- Stride length
- %Swing time R/L
- %Total double support

Customized perturbations

Phase II:
User
training

User Control Unit (UCU)

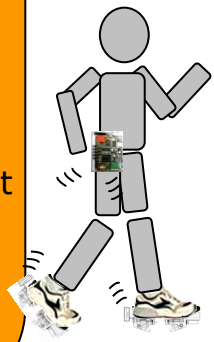


Swing detector

Control

Motors

Change of shoe sole inclination and height



Ergonomics & safety

- Power Supply
  - Power consumption and lifetime
    - Power management (output stage on/off)
  - Battery Type
    - Short circuit Protection
    - Temperature Protection
- Electronic System (uC Based)
  - Reliability of Operation
  - Sensor and Actuator Management
    - Real Time operation
  - Thermal Management
- Wireless Communication
  - Real Time Communication
  - Reliability of Operation

Shoe mechanics & electronics

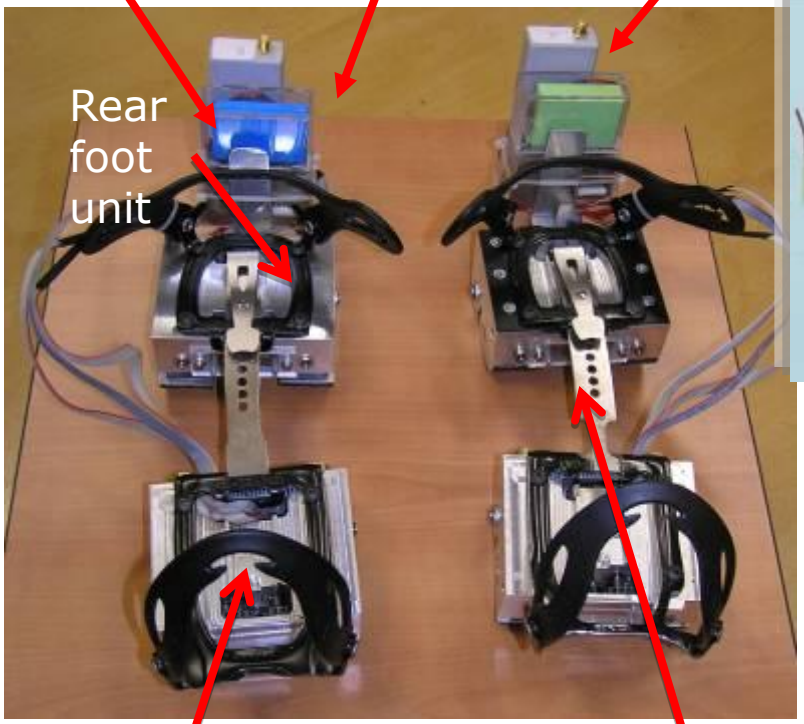
Electronics

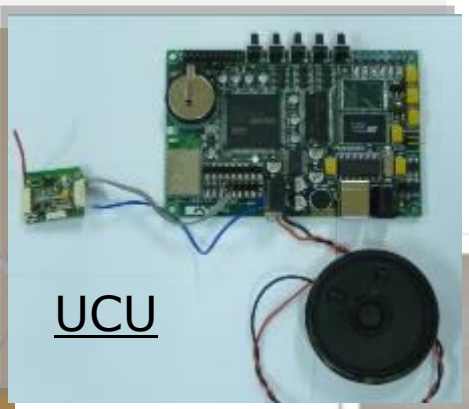
Swing detector/
wireless
communication unit

Battery

Actuators

Rear
foot
unit





UCU

Fore foot unit

Adjustable
length

Strip to fix to the shoe

Lesson Learned ?

- Smiling is still an on-going project
  - Technical design guided by interview to target users
  - Dummy shoes to test shoe weight and height

HOWEVER

- Integration is a big issue!!!
- Challenges: Ergonomics and safety

- Personalization of training, multi-language, supportive audio messages
- User-centered design and design 4 acceptability → Devices to empower the user, augment QoL and self-confidence

VALIDATION ON ELDERLY IS GOING TO START

Conclusions

- ICT technologies may offer novel chances to support the natural ageing process and counteract disability

- Wearable sensing and actuation technologies empower the user to self-care transforming the way people, including the aged, interact with their own health, raising their awareness

- Tight cooperation between clinical and technological experts doubles the value of smart devices and shortens the route to market

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Thank you for the attention!